be forced depended upon the pressure of the steam, and it is interesting to note that Savery occasionally employed pressures as high as eight to ten atmospheres, in copper vessels with joints of hard solder, and, at first, without a safety valve.

The next step in the development of the steam-engine was made by Newcomen, who employed a vertical cylinder with a piston to drive pumps fixed in the mine shaft.

A wooden beam was fixed above, the ends of which formed sectors of a circle struck from the centre of the gudgeon upon which the beam oscillated, the piston-rod at one end and the pump-rods at the other being connected to the beam by flat chains, which were alternately wound and unwound on and off the sectors during working. The cylinder was open at the top, the upper surface of the piston being in contact with the atmosphere. Assuming the piston to be at the bottom of its stroke, steam at about atmospheric pressure was admitted below. The piston rose and the pump-rods descended, allowing the barrel to fill with water. Communication with the boiler was then cut off, and a jet of water from an elevated tank was allowed to enter the cylinder, thus condensing the steam and forming a vacuum. The piston was then forced downwards by the pressure of the atmosphere and the pump-rods raised, lifting the water out of the pump barrel to the surface. Steam was then admitted to the cylinder, allowing the piston to rise, and the products of condensation were forced out of the cylinder through a " snifting " valve.

The efficiency of the Newcomen engine was not greatly superior to that of Savery's. Exactly the same fundamental faults existed. The steam was not used expansively, but was employed merely as a means for producing a vacuum, and was allowed to enter a cylinder which had just previously been cooled by the presence of water. Nevertheless, it was a great step in advance. Newcomen had produced a machine, not merely an apparatus. The depth from which water could be raised depended riot upon the pressure of the steam, for he used very low pressures, but only upon the diameter of the piston and the length of stroke. Later the engine was

improved greatly in detail, especially by Smeaton. All the necessary movements of the various valves were made automatic, and it became thoroughly workmanlike and reliable, so that it was extensively adopted for the pumping of water; but just about this period the improvements effected by James Watt caused it to be rapidly superseded, although survivals of the type were in use until comparatively late in the nineteenth century.

In 1763, James Watt, whilst engaged in repairing a model Newcomen engine used for demonstration purposes at Glasgow University, perceived the great waste caused by the condensing portion of the cycle being allowed to take place in the working cylinder, and he conceived the idea of using a separate vessel as a condenser. He also saw the necessity for removing the air carried in by the condensing water and by leakage, which, of course, impaired the vacuum by its expansion from atmospheric pressure. A pump for removing both the air and products of condensation was employed by